MOKELUMNE WATERSHED AVOIDED COST ANALYSIS:

Why Sierra Fuel Treatments Make Economic Sense

The Nature Conservancy
Protecting nature. Preserving life.

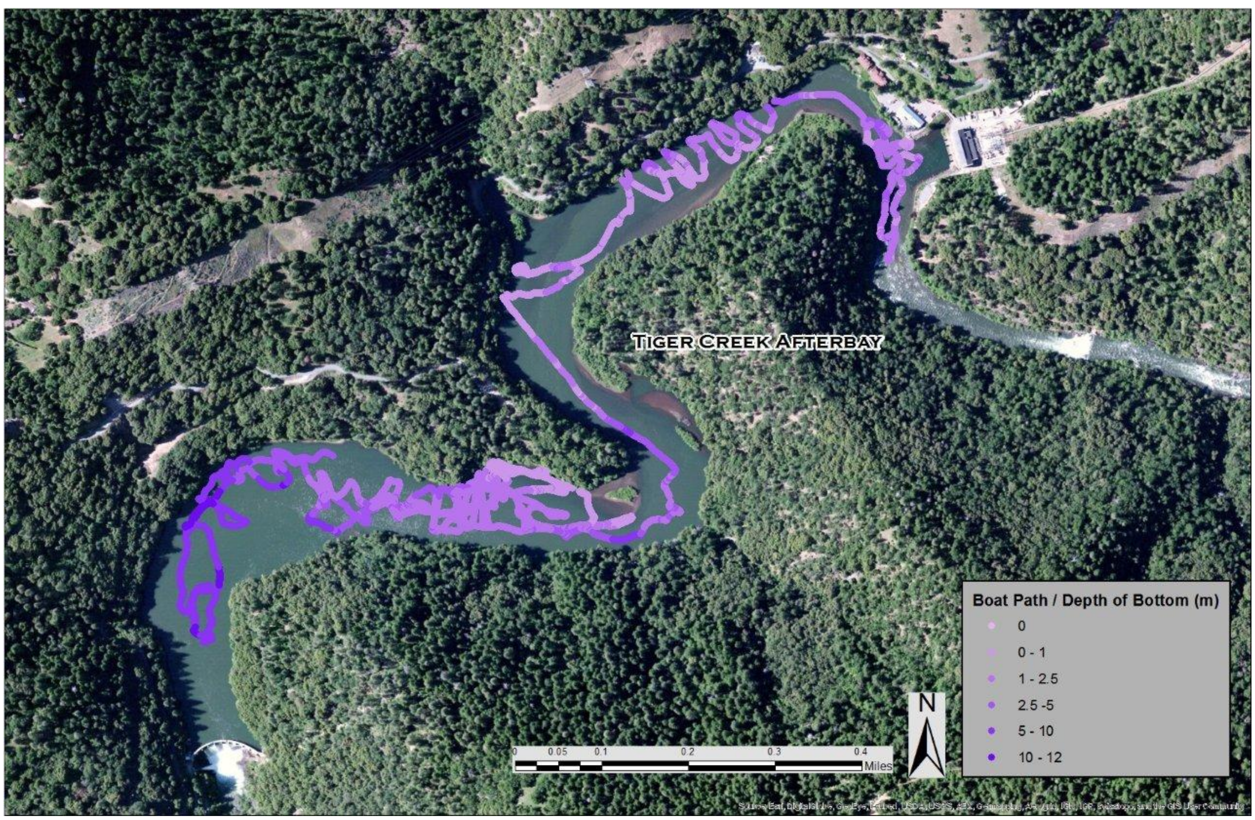
SIERRA NEVADA CONSERVANCY

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Appendix F: Bathymetric Survey - Methods for Calculating the Volume of Tiger Creek Afterbay

On September 5, 2013, Barry Hill, Nic Enstice, and Matthew Bokach surveyed the floor of Tiger Creek Afterbay with a customized radio-controlled bathymetric survey boat produced by Seafloor Systems Inc. Tim Tamplin from Seafloor Systems Inc. was also present. The survey was hampered by some logistical constraints including: the need to keep the boat within reasonable sighting distance; attempting to gain maximal coverage within the limited battery life of the boat; and PG&E's prohibition of any sort of manned boat within the reservoir. Due to these constraints, the closest we were able to get to the downstream dam wall was about 144 meters (Figure F.1). Being mindful of the battery life, our overall strategy was to conduct transects perpendicular to the flow of water in wider areas of the reservoir and collect a single track of data down the center of the reservoir in narrower areas.

Figure F.1: Tiger Creek Afterbay with the purple indicating the data collection point/path of the boat. The darker the purple, the deeper the bottom (in meters).



The shoreline of the reservoir was digitized by starting with the polygon from the National Hydrography Dataset and modifying it to match the treeline visible in a 1-m resolution National Agriculture Imagery Program aerial photograph taken in 2010. Our observation while walking nearly the entire length of the reservoir was that the treeline was very close to the edge of the water. However, because of the presence of "tree islands" within the reservoir and/or depths that were too shallow to run the boat, there were some small areas along the edges (particularly in the center of the reservoir) that were not included in the digitized polygon. The volume of water contained in these areas was estimated by a different process explained below. The shoreline polygon had an area of 205,403 m^2, or 50.66 acres. We converted this polygon to a set of points spaced every meter around the polygon perimeter. The depths of these points were set to 0 everywhere except along the dam wall and at the outflow structure at the upstream end of the reservoir. Depths at these points were set equal to the nearest bathymetric point collected.

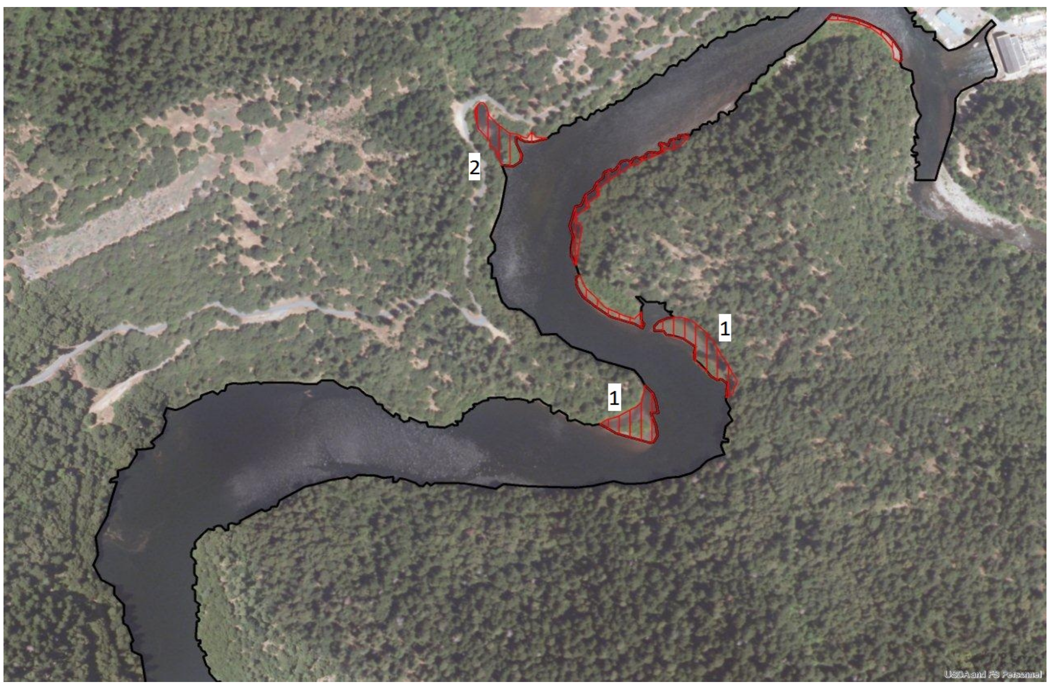
Following their collection in the field, in the office the bathymetric points were "cleaned" visually by looking at them in three-dimensions relative to a polygon of the reservoir surface that was defined as depth = 0. The cleaning heuristic was a smoothing one where points that deviated horizontally from the path of the boat were removed, as well as any points that introduced noticeable vertical discontinuities. Most of the removed points represented either: a) expected "drift" due to the time interval of GPS collection being faster than that of sonar collection; or, b) data collected when the boat was stationary (e.g., near shore or during downtime as operators were discussing their strategy). Tim Tamplin also indicated that the amount of vegetation visible at the bottom of the reservoir would reduce the accuracy of the sonar data, although the smoothing nature of the cleaning heuristic should have removed much of this "noise" from the data. Finally, any survey points that fell outside the digitized shoreline of the reservoir were removed. After cleaning, 24572 (54.9%) of the original 44792 points remained.

The bathymetric survey took place between 10:14am and 3:35pm. Stage readings collected every half hour during this time period and acquired from Chris Bennett at PG&E indicated that the stage level dropped linearly (r^2 = 0.9997) from 710.3486 meters above sea level to 710.0956 meters above sea level during this period. The regression equation relating stage to time was used to convert the sonar depths to elevations. Sonar depths were subtracted from the stage corresponding to the time of depth data acquisition to provide elevations for the lake bed. Shoreline points at depth = 0 were set to 710.3486 meters.

The Inverse-Distance Weighted (IDW) tool in the Spatial Analyst toolbox of ArcGIS was used to interpolate a three-dimensional surface of the reservoir's floor. The inclusion of zero-depth points along the shoreline forced the interpolated surface upward along the edges. Due to the inadequacy of the collected points to interpolate the entire area of the reservoir, points were densified by dropping lines between shoreline points and their nearest bathymetric points, and interpolating depths linearly at either the quintiles of these lines (i.e., four evenly-spaced points per line); or, in the case of lines that were longer than 80m, at the deciles (i.e., nine evenly-spaced points per line). The initial set of such lines were created at shoreline points spaced every 50m around the perimeter, and subsequently densified by half the distance iteratively, until enough such points had been created within an area that the IDW tool could interpolate a surface for the entire area of the reservoir. For most of the reservoir, these densification lines were needed every 12.5 meters until enough were present to interpolate the surface. In all, 1532 such "interpolation" points were required. The resulting interpolated surface covers 95.7% of the area of the shoreline polygon.

The reservoir volume was estimated by subtracting the interpolated floor surface from the zero-depth elevation of 710.349 meters. To estimate loss of capacity since the reservoir was created in 1931, we had to adjust this base elevation to match the 1931 crest of 713.232 meters above sea level. We added the additional 2.883 meters of water to the entire digitized polygon, and also added the areas around the edges that would be inundated at this higher stage[1] plus the 4.3% of the polygon that was not included in the interpolated surface (an additional 15,166 m^2) at the same depth (Figure F.2). This resulted in an estimated volume (at a stage of 713.232 meters) of 1,158,974.1 m^3. Compared to the 1931 capacity estimate of 4,884,588 m^3, this represents a loss of 76.3% of the reservoir's capacity since its creation (Table F.1).

Figure F.2: Tiger Creek Afterbay with red-hashed areas that were added in the digitization process to approximate the shoreline at original capacity.



[1] To calculate the higher stage, we used the same NAIP image to digitize the inundated portions of the reservoir that were not included in the main polygon. This included the areas behind the "tree islands" (1's on map), and a "pseudo-bay" that extends to the north (2 on map).Our working assumption was that the treeline reflects the area not consistently inundated for roughly the last 30 years, and hence the present water level is indicative of the overall average water level for the past couple decades. Unfortunately the Digital Elevation Model (DEM) data suggested that the reservoir is smaller than it presently is when we adjust for the stage to be at the 1931 level. Therefore, the treeline and the current inundation levels were all we could rely upon to estimate the appropriate shoreline.

Table F.1: Tiger Creek Afterbay estimated capacity based on 2013 bathymetric survey.

Reservoir	*Date Built*	*Drainage area (km2)*	*Initial Capacity (m3)*	*Estimated 2013 Capacity (m3)*	*% capacity*	*Sedimentation (m3)*
Tiger Creek Afterbay	1931	932.4	4,884,589	1,158,974.1	24%	3,725,614.9

In 2009, Minear and Kondolf[2] published a study on estimating sedimentation rates within reservoirs in California. Applying their methods to Tiger Creek Afterbay, we calculated a remaining capacity of 1,812,021 cubic meters, which is just over 10% more capacity than we calculated via the bathymetric survey. Both methods have their levels of uncertainty and assumptions, but the close proximity of the two independent results suggests that it is likely that Tiger Creek Afterbay has less than 50% capacity remaining. A more rigorous bathymetric survey of the Afterbay would help refine the estimate.

Table F.2: Tiger Creek Afterbay estimated capacity based on a study by Minear and Kondolf[2].

Reservoir	*Initial Capacity (m3)*	*Sedimentation rate (m3/km2/year)*	*Estimated 2012 Capacity (m3)*	*% capacity*	*Sedimentation (m3)*
Tiger Creek Afterbay	4,884,589	97	1,812,021	37%	3,072,568

[2] Minear, J. T., and G. M. Kondolf (2009), Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California, Water Resour. Res., 45, W12502, doi:10.1029/2007WR006703.

Mokelumne Watershed Avoided Cost Analysis: Why Sierra Fuel Treatments Make Economic Sense

Report Version 1.0

April 10, 2014

Citation Suggestion:

Buckley, M., N. Beck, P. Bowden, M. E. Miller, B. Hill, C. Luce, W. J. Elliot, N. Enstice, K. Podolak, E. Winford, S. L. Smith, M. Bokach, M. Reichert, D. Edelson, and J. Gaither. 2014. "Mokelumne watershed avoided cost analysis: Why Sierra fuel treatments make economic sense." A report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and U.S. Department of Agriculture, Forest Service. *Sierra Nevada Conservancy.* Auburn, California. Online: http://www.sierranevadaconservancy.ca.gov/mokelumne.

Disclaimer

This report is rich in data and analyses and may help support planning processes in the watershed. The data and analyses were primarily funded with public resources and are therefore available for others to use with appropriate referencing of the sources. This analysis is not intended to be a planning document.

The report includes a section on cultural heritage to acknowledge the inherent value of these resources, while also recognizing the difficulty of placing a monetary value on them. This work honors the value of Native American cultural or sacred sites, or disassociated collected or archived artifacts. This work does not intend to cause direct or indirect disturbance to any cultural resources.

Produced in cooperation with the USDA Forest Service. USDA is an equal opportunity provider and employer.

Contact Information

For More Information:		
The Nature Conservancy — Protecting nature. Preserving life.	Sierra Nevada Conservancy	Forest Service, U.S. Department of Agriculture
David Edelson dedelson@tnc.org **Kristen Podolak** kpodolak@tnc.org	**Kim Carr** kim.carr@sierranevada.ca.gov **Nic Enstice** nic.enstice@sierranevada.ca.gov	**Sherry Hazelhurst** shazelhurst@fs.fed.us